

P-sec Magnetization Dynamics of Vortices Probed at High Spatial Resolution



Collaboration between ALS & SSRL, FU Berlin

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Study of Phase Transitions in Solids



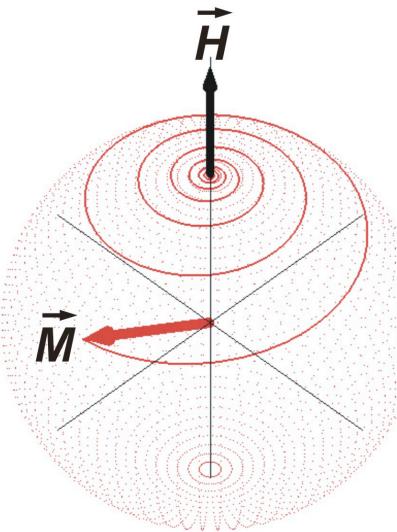
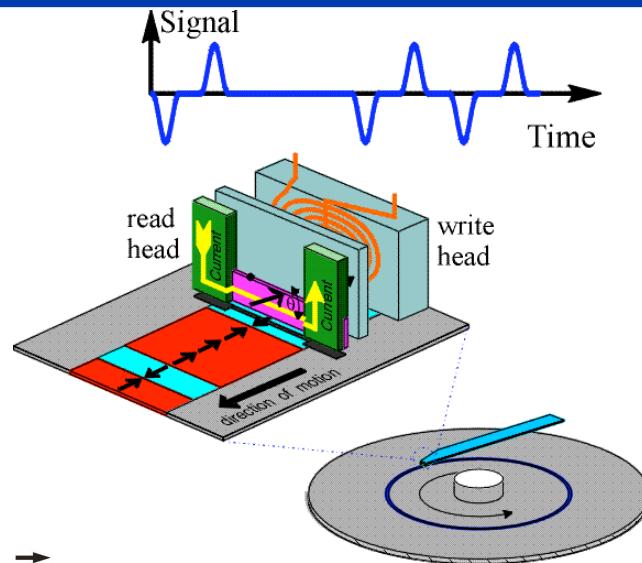
- Structural transitions.
- Electronic transitions: Magnetism, spin reorientation, ferroelectricity, charge and orbital order, superconductivity

X-rays measure the order parameter

Structural transitions
Orbital, charge order
Ferroelectricity
Magnetism
Superconductivity

Lattice structure
Electronic structure
Lattice structure, anisotropy
Magnetic moment (FM, AFM)
Superconducting gap

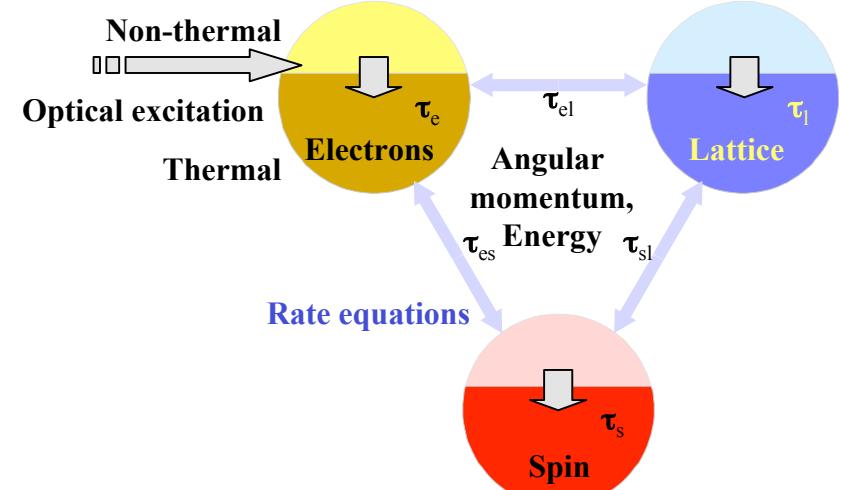
Magnetization & Spin Dynamics



**Field-driven magnetization
precession, domain wall motion**

Applications: hard disk / spintronics.

**Goal: Manipulate magnetization
more quickly and efficiently.**

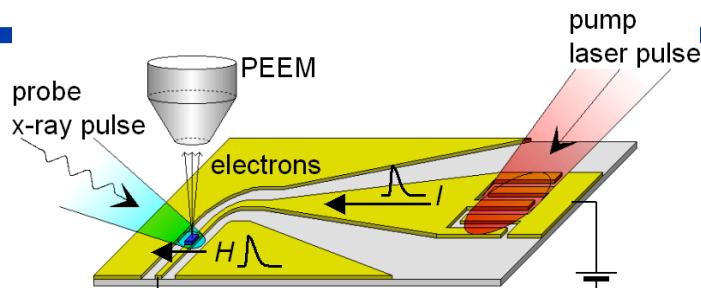


Ultrafast phase transitions

How to Manipulate a Magnetic System?

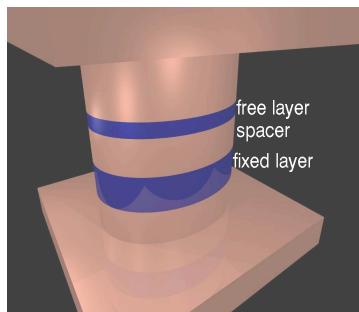


Field pulse



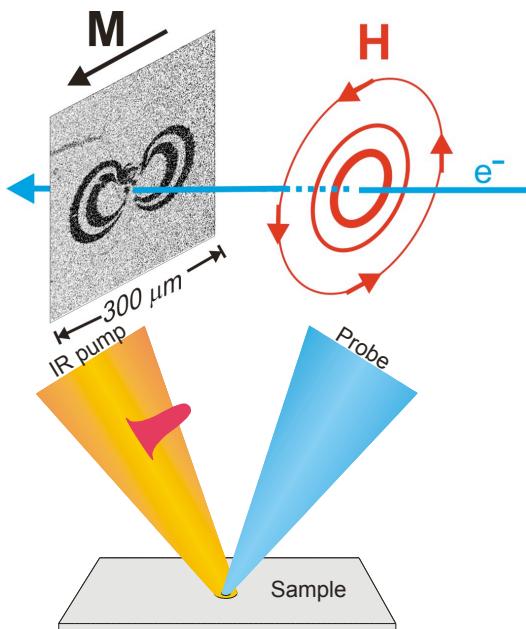
GaAs switch
100 ps
200 mA
20 mT

Spin injection



GaAs switch
~ ps
10 mA

Linac field pulse (H.C. Siegmann et al.)

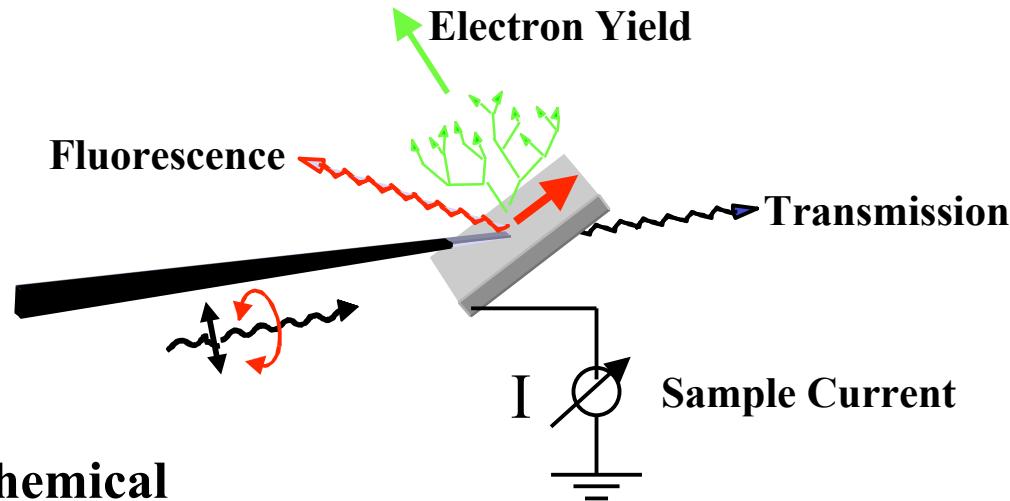


100 fs
many T

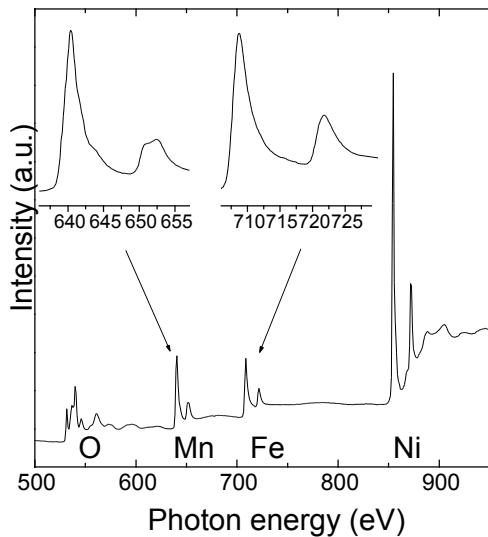
Optical pulse

Ti:S laser
30 fs
1 mJ

Magnetism & Soft X Rays



Elemental, chemical specificity



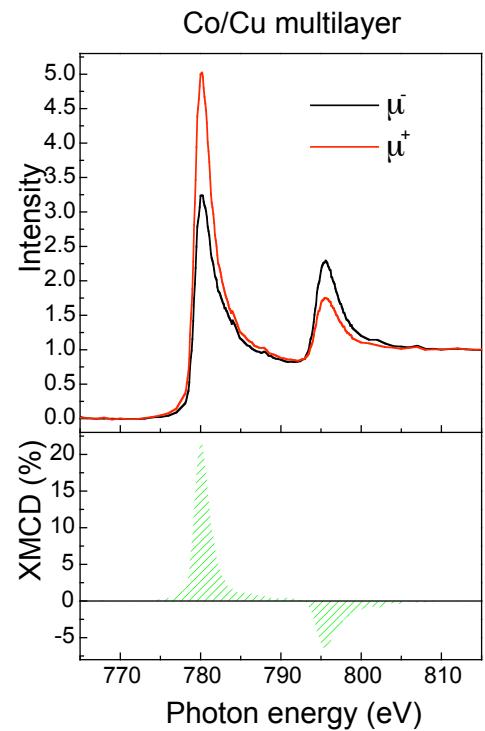
Sum rules

$$m_s = \frac{3}{P \cos \varphi} n_d \frac{A_{L3} + 2A_{L2}}{A_{iso}}$$

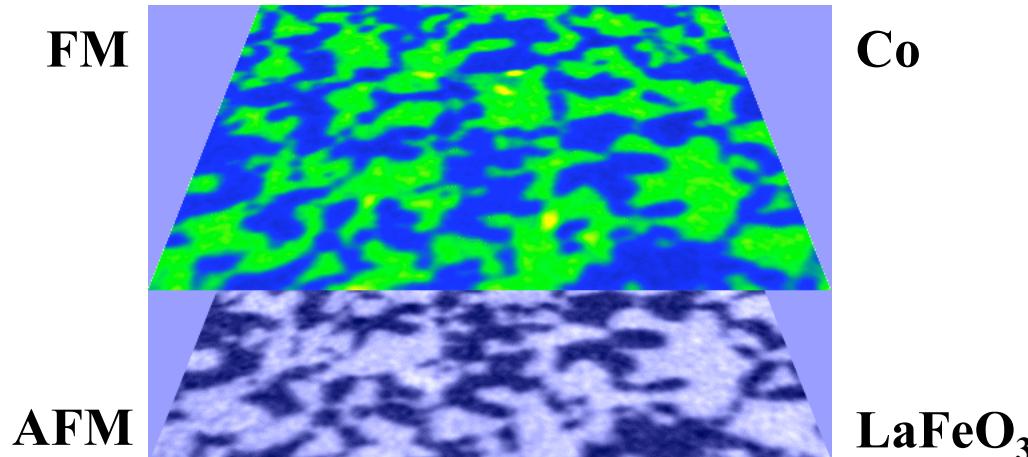
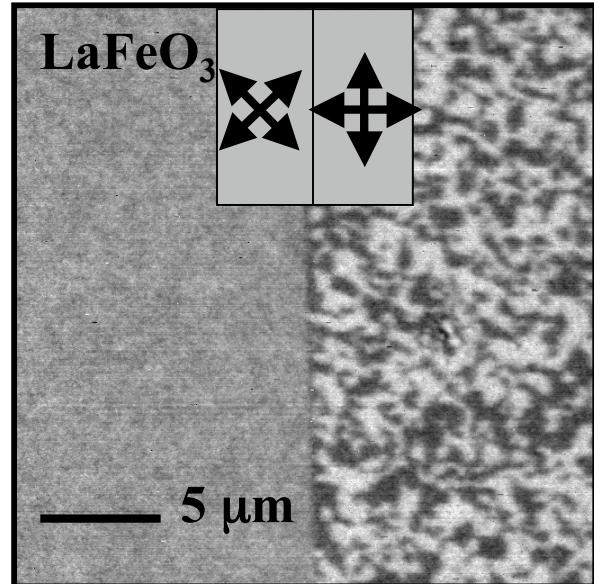
$$m_l = \frac{2}{P \cos \varphi} n_d \frac{A_{L3} - A_{L2}}{A_{iso}}$$

Quantitative, measures spin and orbital moment

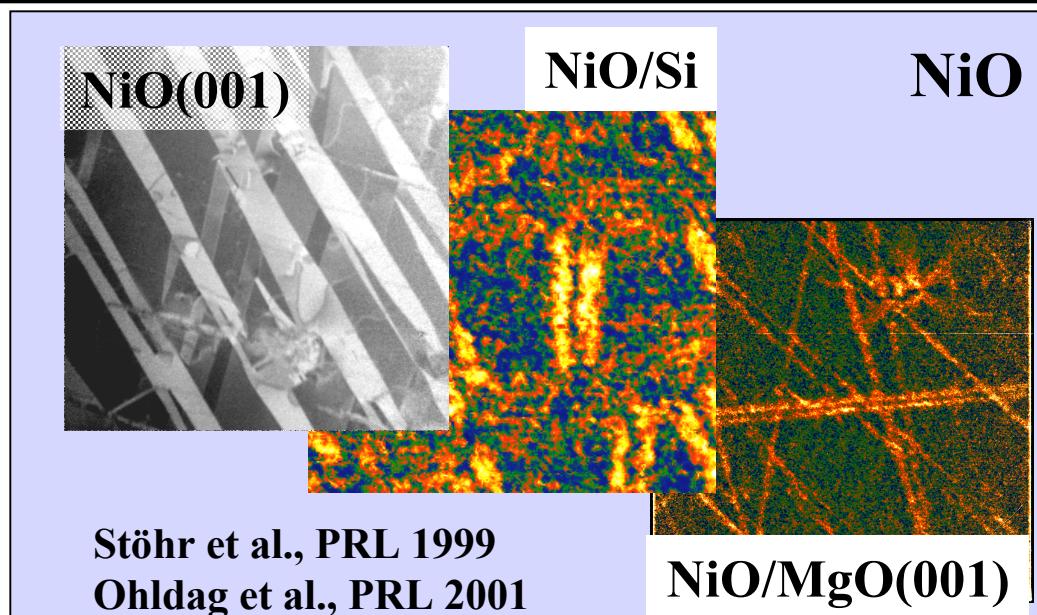
X-ray magnetic circular dichroism



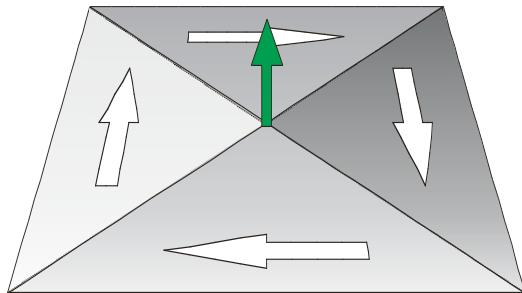
Highlights – Antiferromagnets/Exchange Bias



A. Scholl et al., Science 2000
F. Nolting et al., Nature 2000



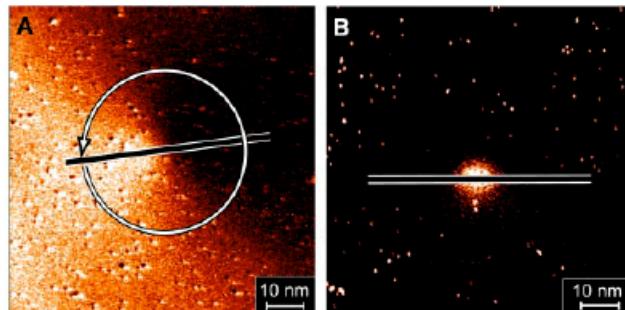
Vortex Dynamics



First measurement of core dimension
in Fe/W(110) using SP-STM:

Direct Observation of Internal Spin Structure of Magnetic Vortex Cores

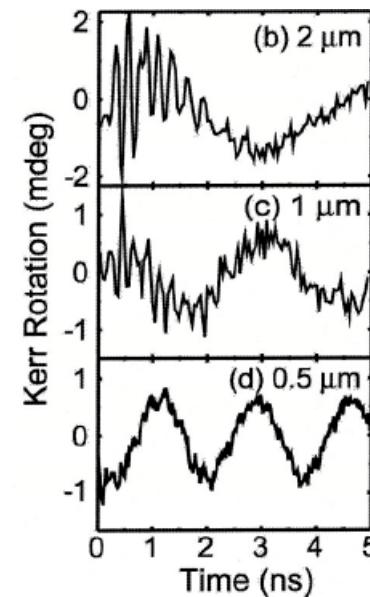
A. Wachowiak, J. Wiebe, M. Bode,* O. Pietzsch,
M. Morgenstern, R. Wiesendanger



18 OCTOBER 2002 VOL 298 SCIENCE www.sciencemag.org

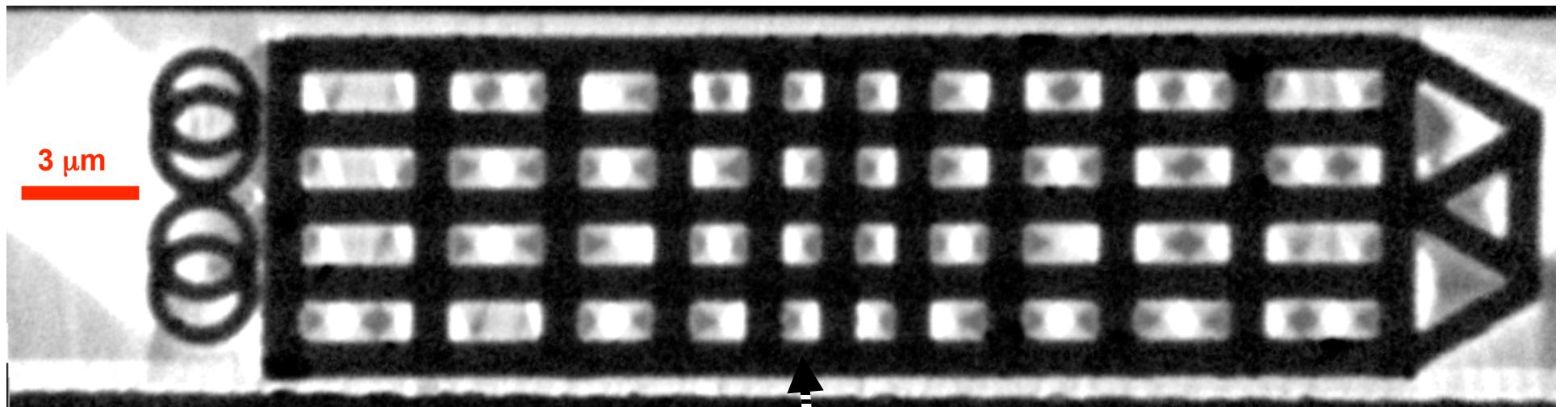
First observation of a vortex core using AFM:
T. Shinko et al., Science 289, 930 (2000)

Kerr microscopy observes gyro mode

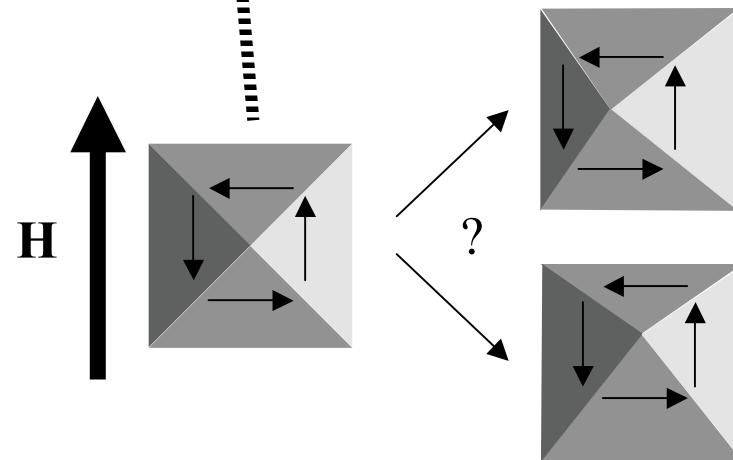
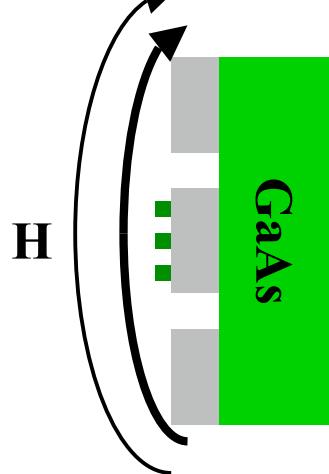


J.P. Park et al., PRB 67, 020403

Magnetic Configurations in μ m Patterns

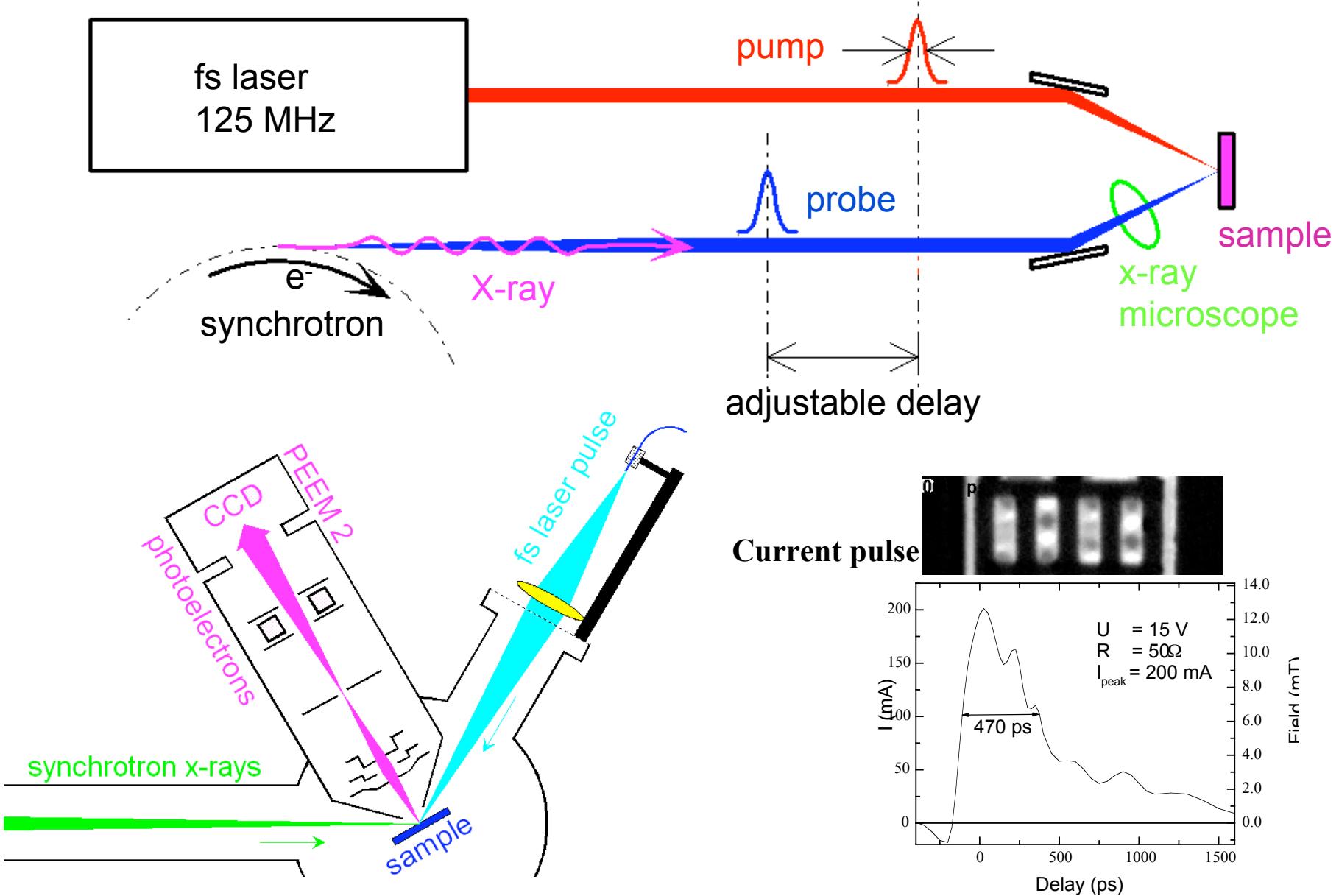


20 nm CoFe

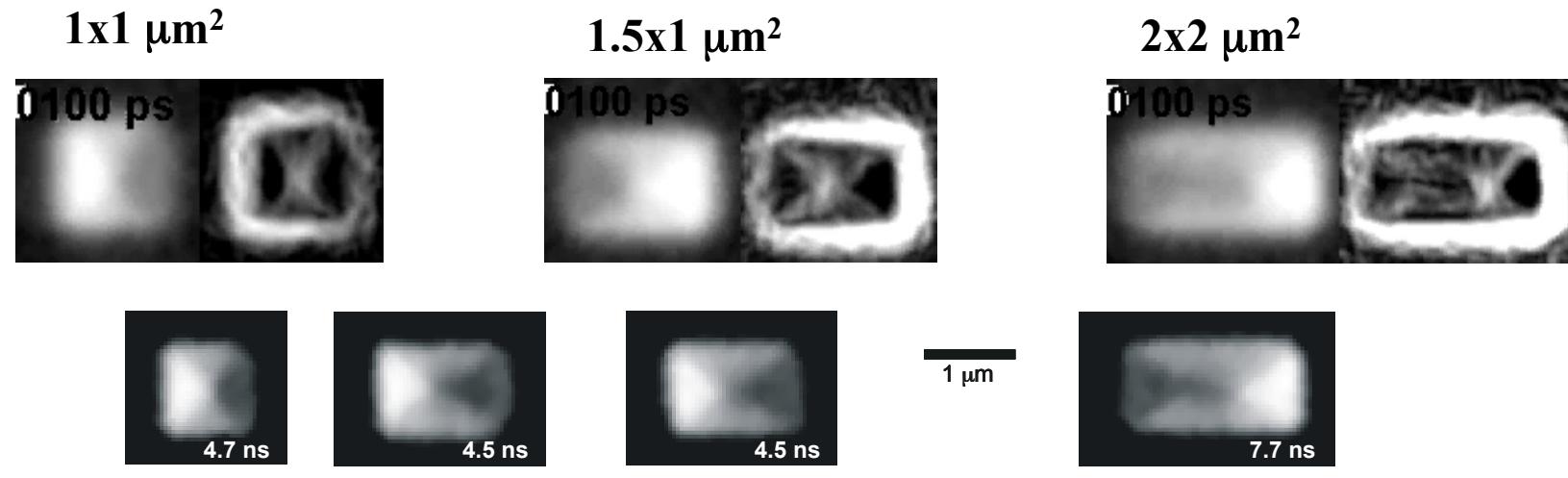


In which direction will the vortex core move?

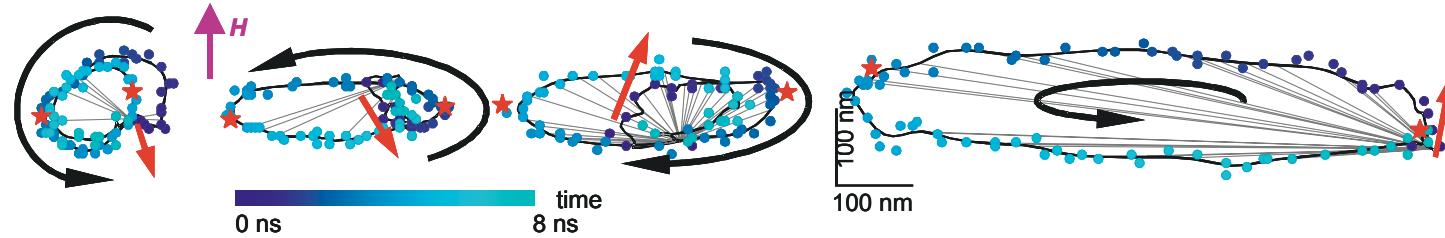
Experimental Setup



Vortex Dynamics

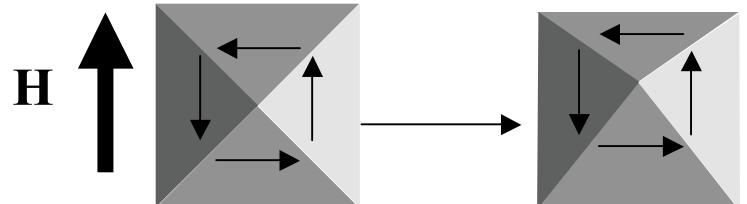


Core trajectories

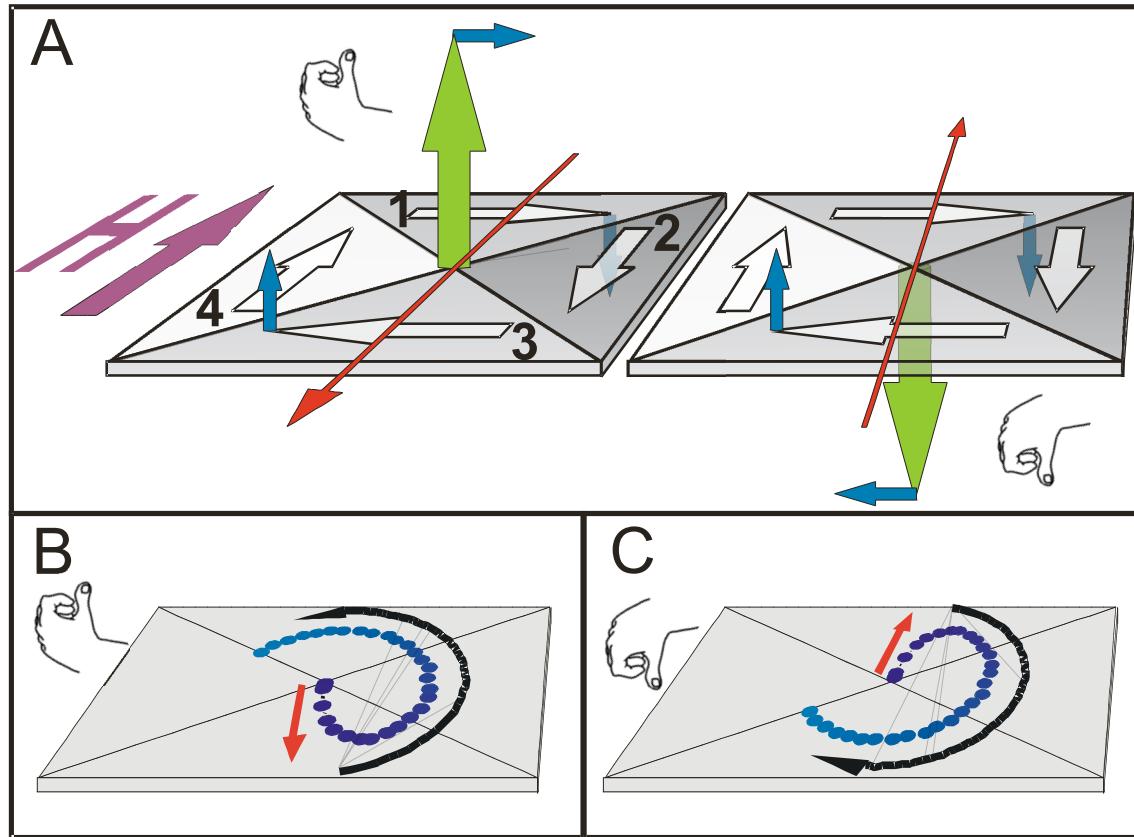


- Initial acceleration (anti-) parallel to field pulse!
- Followed by gyrotropic rotation.

S.B. Choe et al., Science 204, 420 (2004)



Micromagnetic Model

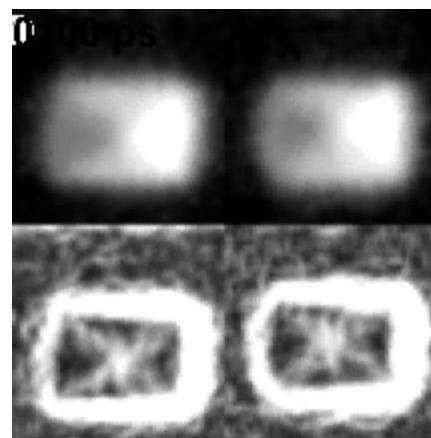


- Out-of-plane core magnetization induces a handedness or chirality
- Vortex core is accelerated along the field by precession

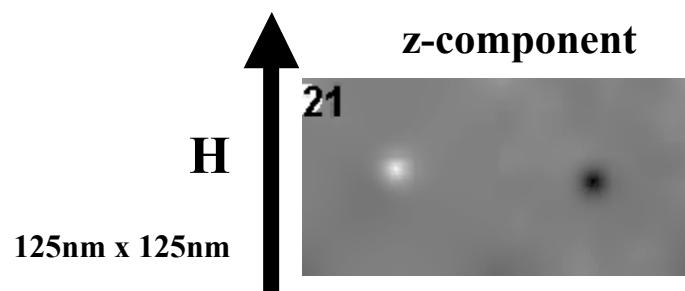
Chirality Determines Fast Dynamics



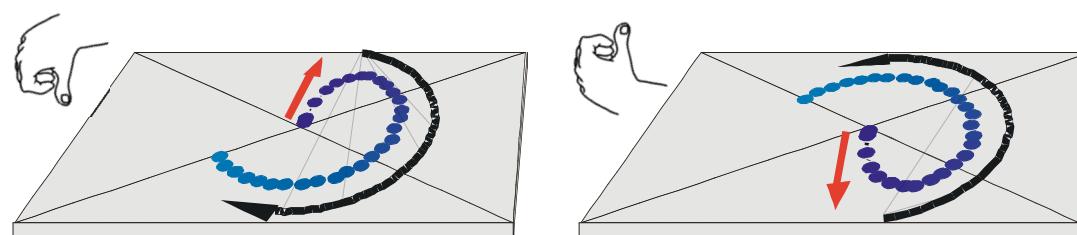
1.5 μm x 1 μm



Vortex rotate oppositely although patterns similar



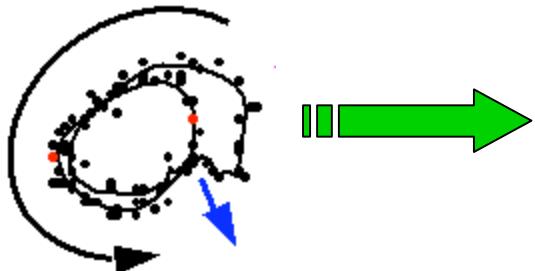
Simulation shows that orientation depends on vortex chirality



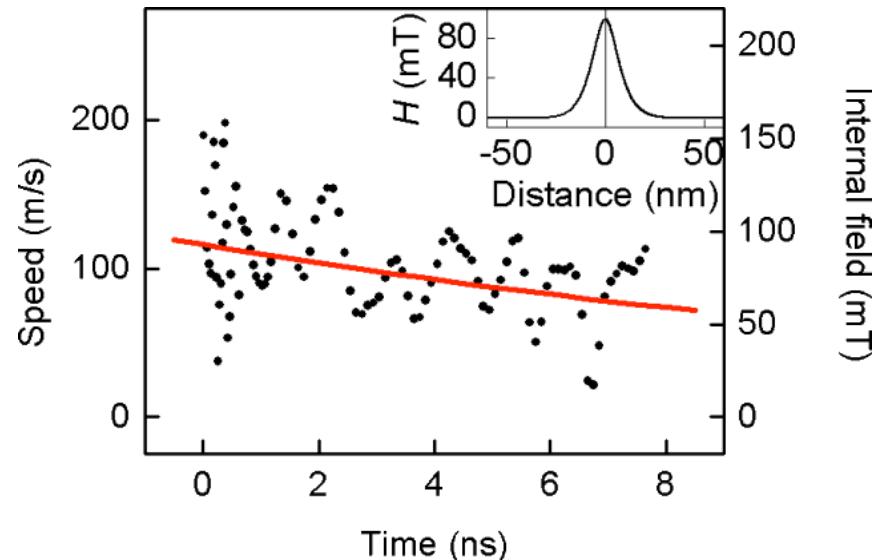
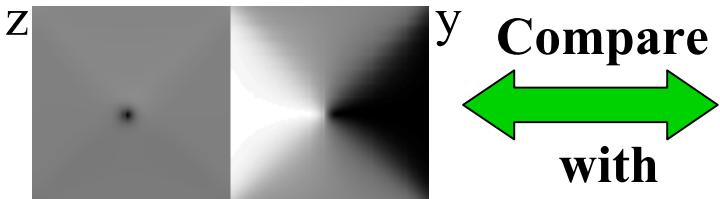
Effective Field at Vortex Core



Trajectory



Micromagnetic simulation



Effective Field at vortex core: $\approx 80 \text{ mT}$

Field pulse: $\approx 15 \text{ mT}$

Estimated field (static susceptibility): $\approx 3 \text{ mT}$

Our Real Goals



<u>Magnetization dynamics</u>	<u>Spin dynamics</u>
Physics understood	New physics
Systems complex	Model systems
Technological impact	Scientific impact
Time scale ~100 ps	Time scale <<100 ps
Microscopy	Spectroscopy

Electron and Spin Dynamics



**Investigate spin, orbital, charge dynamics
during f-sec laser-driven phase transitions**

- Demagnetization
- Magnetization reorientation
- Ferromagnet – antiferromagnet transition
- Metal – insulator transition (charge order, orbital order → spin order)
- Ferroelectricity
- Superconductivity

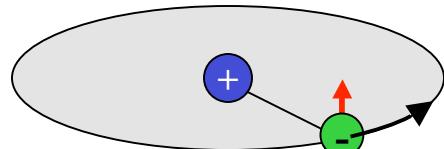
X-rays directly sense order:

- spectroscopy (photoemission, absorption, dichroism)
- scattering, diffraction

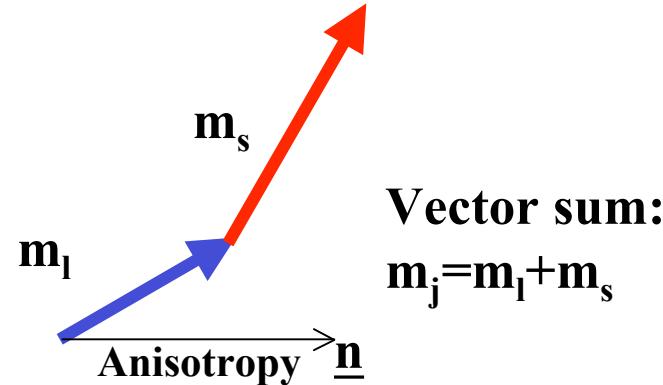
Spin, Orbital Momentum & Anisotropy



Orbital momentum: $-\mu_B l$



Spin momentum: $-2\mu_B s$



- m_l and m_s are coupled by the **spin-orbit interaction**.
- m_l is coupled to the lattice by the **anisotropic crystal field**.

In an ultrafast experiment, measurement of spin and orbital momentum provides information about the **flow of angular momentum** and about the **time-dependent magneto-crystalline anisotropy (MCA)**.

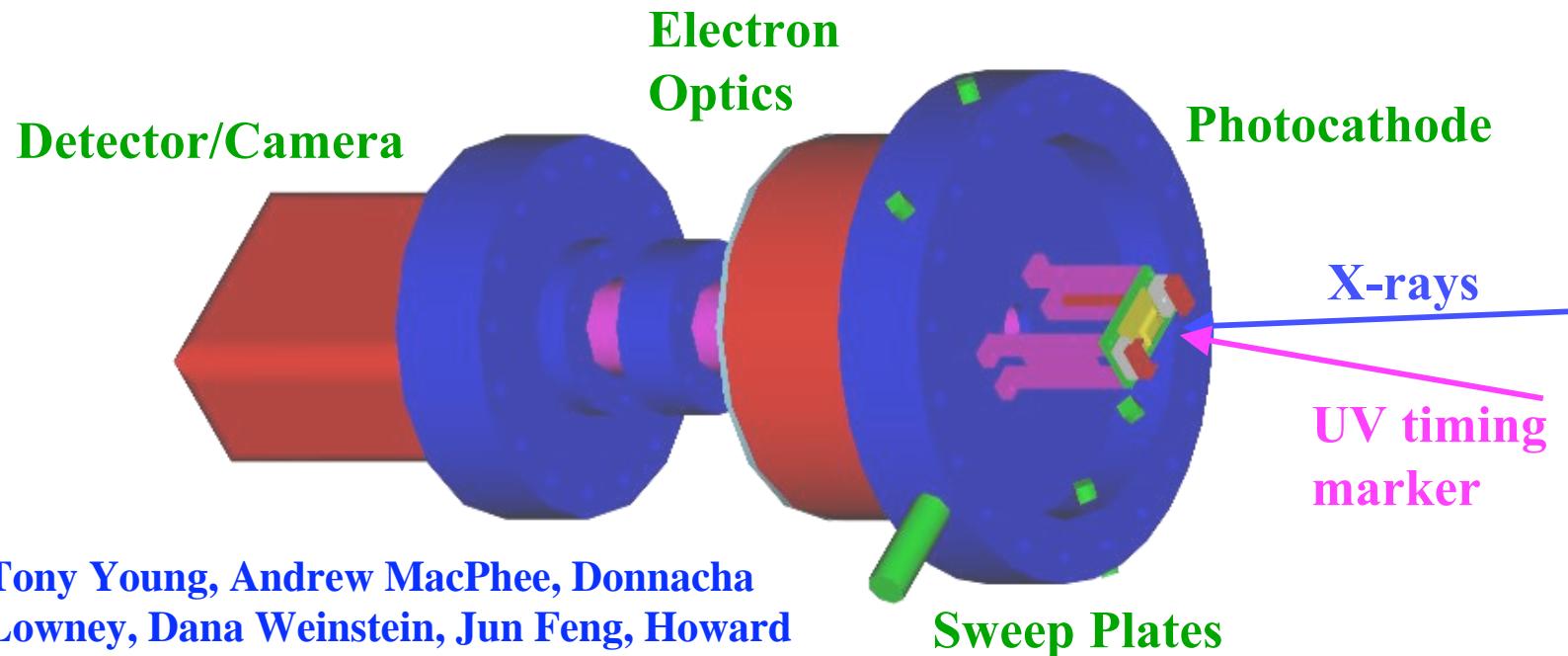
Coming: Streak Camera Detection



Improve time resolution to below 1 ps using streak camera

Future: New f-sec x-ray sources:

- Optimized for spectroscopy: tunable, stable, polarization control
- High repetition rate: enables electron spectroscopy, microscopy



Tony Young, Andrew MacPhee, Donnacha
Lowney, Dana Weinstein, Jun Feng, Howard
Padmore, Ernie Glover, Jamie Natasche

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Squaw Valley, April 2003